Middle School
Teaching Guide

Temperature Grapher

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HRM software
A division of Human Relations Media

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TEMPERATURE GRAPHER

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A Microcomputer Program for the
Apple II Computer

Foreword

Temperature Grapher is one of a series of programs developed during the summer of 1981 in a project coordinated by the National Science Teachers Association, Project for an Energy Enriched Curriculum (PEEC) and Technical Education Research Centers (TERC), with funding from the U.S. Department of Energy. The project involved teachers and student programmers. The goal of the project was to develop sophisticated software dealing with various topics in energy studies. The pilot programs were widely tested in schools across the country and revised in the spring of 1983. This software is designed to be used in school curricula in a variety of applications. Some of the programs are best used in the classroom, while others may be used in resource rooms, computer rooms, and possibly in the home. These materials are most appropriate for grades 9 through 12, though they may be used with older and younger students. The activities can last for a number of weeks or class periods depending on the teacher.

Other programs in this series are these:

Home Energy Savings	This is a game that illustrates the economics of various energy-conserving home improvements.
Power Grid	This is a game in which the student has responsibility for the operation of a mix of power-generating facilities. The object is to meet consumer demand as efficiently as possible.
Energy Conversions	This program shows how to make conversions from one energy unit to many other types of energy units.
Personal Energy Inventory	This program allows for a wide range of data analysis of students' personal energy use.
Electric Bill	This program introduces and teaches the calculation of an electric bill with text and graphics.

All programs are available for both Apple II* and TRS-80* Model III and Model IV computers with the exception of Temperature Grapher, which is available only for the Apple.

Summary of Temperature Grapher

The Temperature Grapher program provides the user with a valuable interface between the science laboratory and the Apple computer. The program and the accompanying temperature probes allow students to generate a display of temperature versus real time on a line graph. The program is designed to give the user a number of options in setting the parameters of time and temperature. It can read and display either one or two temperature readings. The axes can be either labeled or unlabeled. A variety of other options exist.

Temperature Grapher can be used successfully in a wide range of teaching environments from elementary to graduate school. It is designed to be a supplement to the lab equipment normally available. It can be used at any level for the investigation of heat, temperature, and energy-related phenomena.

Scientists and engineers routinely use computers to assist them in their investigations. Students should become familiar with the valuable contribution that computers can make in the laboratory.

Objectives of Temperature Grapher

1. To provide teachers and students with a new laboratory tool that displays temperature in real time on the computer.

2. To provide teachers and students with a flexible computer program that facilitates maximum use in the laboratory.

3. To provide teachers and students with an introduction to the wide uses of computers in scientific instrumentation.

Materials Supplied

The Temperature Grapher package contains a program disk, all necessary hardware and this Teaching Guide. The disk will run on all Apple II+ and IIe microcomputers and any Apple II with DOS 3.3, 48K RAM, and Applesoft BASIC in ROM. If the Apple II is an earlier machine with Integer BASIC in ROM, a language card (16K memory card) is necessary. The program on the disk provides for a number of experimental options. The hardware comprises two temperature probes and two extender cables joined inside a connector that plugs directly into the Apple game-paddle input inside the Apple. The temperature probes are sensitive thermistors, semiconductors that change their electrical resistance in response to temperature change. This change is measured by the computer and converted to numerical and graphical data displayed on the screen. The hardware is relatively simple; the program that uses the hardware is relatively sophisticated. This Teaching Guide gives instructions for using the program and temperature probes in several subject areas that relate to teaching about energy.

Background Information

Laboratories in research and industry are filled with computers. Even the smallest research facilities rely on computer data collection. Nearly every student has at least seen (if not used) a digital blood pressure reader or a digital thermometer in a doctor's office or hospital. One visit to a chemistry or physics laboratory at a college campus will demonstrate the wide use of computers in scientific instrumentation. Temperature Grapher is important not only for the exact specifics of temperature display but also, in a larger sense, for a demonstration of the laboratory-computer interface.

Temperature Grapher has many applications in the study of temperature-related phenomena. Since the program is a laboratory tool, it is not necessary to detail step by step the experiments that must be done using this tool. Instead, a number of suggested experiments will be briefly outlined as examples of the use of Temperature Grapher at various grade levels and in several disciplines.

Specifically, this program can be used with a large number of energy education materials. The computer display of temperature is ideal in studies of solar collection design, passive solar experiments, heat flow, heat capacity of materials, efficiency of fuels, and many other topics. An abundance of energy education material is available to the teacher, much of it free or inexpensive. Three sources are listed below.

- Energy Environment Source Book, National Science Teachers Association, 1742 Connecticut Ave., NW, Washington, DC 20009.

- Energy and Education newsletter with up-to-date information in the field. Available by subscription from the above address.

- Your local utility company.

Teaching Strategies

Temperature Grapher has applications in a wide range of teaching situations. A few examples are given below.

For elementary/middle school students

1. Display weather information as a graph on the screen.

2. Have students design simple solar collectors and use the Temperature Grapher to evaluate the efficiency of different designs.

3. Ask students to design a device to insulate an ice cube so it won't melt. Keep track of the temperature change with Temperature Grapher.

4. Investigate the flow of heat in the classroom by taking readings at different spots in the classroom--ceiling, windows, floor.*

For high school students

1. Temperature Grapher can be used in any experiment where temperature is measured, particularly in experiments related to energy and conservation of energy (see experiments above). See also the following.

2. In chemistry, use Temperature Grapher in such experiments as boiling-point determination, cooling curves, heats of reaction, etc.

3. In physics, use Temperature Grapher to record changes in temperature in physical processes. In the study of light, investigate the efficiency of light bulbs by measuring the heat produced.

4. In biology, graph the changes in skin temperature on different parts of the body.

5. To extend classroom work, students can visit a research laboratory at a university or industry to see instrumentation in science and engineering. Students can design their own experiments to make use of Temperature Grapher.

The final section of this guide, "Energy-related Experiments," describes in detail a number of basic investigations you can carry out.

* Additional extender cables are available in radio or electronics supply stores; they are called phono cables.

Starting the Program

This program will run on all Apple II+ and IIe microcomputers and any Apple II with DOS 3.3, 48K RAM, and either Applesoft BASIC in ROM or a 16K RAM card (a language card).

To Start the Program--

1. Insert the disk into the disk drive.

2. Turn on the video screen and the computer.

3. Wait for the program to load, and as soon as directions appear on the screen, start the program as directed.

4. If you have any problems starting the program, check with a qualified person.

Operating the Program

The program is menu driven. This means at each step in the program you will be presented with a menu of choices. After the introduction, the menu that first appears is the Temperature Probe Menu. You may pick one of the following:

```
1 = GRAPH TEMPERATURE PROBE ONE.

2 = GRAPH PROBES ONE AND TWO.

? = NEED HELP!

E = END THE PROGRAM.
```

The important choice here is whether to graph one or both probes. If this is your first time, choose one by typing "1" and pressing "RETURN." This will graph just probe one (the black one).

The second menu that appears is the Graphing Menu. You may pick one of the following:

```
S = START THE GRAPH.

L = LIST OF GRAPH PARAMETERS THAT
    CAN BE CHANGED.

? = NEED HELP!

M = RETURN TO TEMPERATURE PROBE MENU.
```

The important choice here is whether to start graphing now or to change the parameters for graphing. If this is your first time, type "S" and press "RETURN" to start graphing.

When the graph is on the screen there is not enough room to display all the menu choices available, so they are displayed beforehand.

```
R = PLOT A REFERENCE ARROW ON THE
    TEMPERATURE AXIS CORRESPONDING TO
    THE TEMPERATURE OF THE PROBE OR
    PROBES.

F = FREEZE THE GRAPH; PRESS ANY KEY
    TO CONTINUE.

T = PRINT THE TEMPERATURE IN THE LOWER
    LEFT CORNER; PROBE ONE ON THE LEFT,
    PROBE TWO ON THE RIGHT.

M = STOP AND RETURN IMMEDIATELY TO THE
    GRAPHING MENU.
```

The important one to remember is M, which stops the graph and returns you to the graphing menu. When you are ready to start graphing, press any key.

Experiment with Temperature Grapher. Measure all the different temperatures around you. Try moistening the probe and waving it in the air. Will the temperature fall below that of the air in the room? Try changing parameters. If you need more information, type "?" and press "RETURN." Detailed information will appear on the screen.

Calibrating the Temperature Probes

In order to get accurate readings from the temperature probes provided in the Temperature Grapher package, you must first calibrate them, using the CAL program on the disk, and save the calibration in the computer. This program calculates the three constants A, B, and C for a polynomial equation of the form $Y = A + Bx + Cx^2$. This is an equation for a curve which approximates the resistance-temperature function of a particular set of temperature probes connected to a particular Apple computer. You will need to rerun CAL if you change computers or change temperature probes.

Instructions for running CAL (the calibration program)

1. Gather the necessary equipment:
   - Apple computer
   - Temperature probes
   - One, two, or three Celsius thermometers
   - Three containers of water at different temperatures: one each cold, lukewarm, and hot (approximately 5, 30, and 70 degrees C)
   - The program disk

2. Remove the cover from the computer. Plug the temperature-probe connector through the back slot into the game-paddle input as shown in Figure 1. Insert the temperature probes into the extender cables. One cable and one probe will be coded with black; the other will be coded with red. Make sure you insert the black probe into the black extender cable coming from the computer. Insert the red probe into the red extender cable. From now on the black probe will be referred to as probe one and the red probe as probe two. Replace the cover.

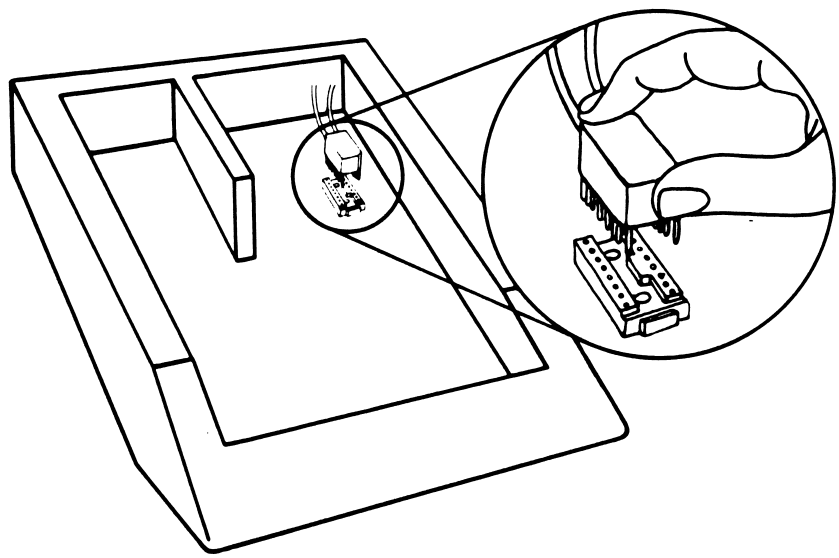

Figure 1

3. Set up the containers of water, and place a thermometer in the cold water. If three thermometers are available, place one in each container.

4. Place the disk in the disk drive, and turn on the computer and video monitor. When the Temperature Grapher introduction appears on the screen, stop the program by continuing to the first menu and choose selection "E" (END). Now type "RUN CAL" and press "RETURN." This will load the program and start it running.

   The program will display the following menu:

```
A = CALIBRATE TEMPERATURE PROBES
    ONE AND TWO.

B = DISPLAY TEMPERATURE OF PROBES
    ONE AND TWO.

C = SEE THE CURRENT CALIBRATION
    CONSTANTS/SAVE THEM ON DISK.

? = HELP!

E = END
```

Choose "A" by typing "A" and pressing "RETURN." The program will tell you what to have ready and ask if you want to continue with the calibration. Type "Y" to calibrate the probes.

5. The computer will instruct you to place both probes with the thermometer in the cold water. When the temperature of the probes and thermometer have stabilized (wait at least 30 seconds), read the thermometer and type the temperature into the computer and press "RETURN." The same process is repeated for the lukewarm water and the hot water.

   When the calculation is done, a reminder will appear on the screen to check the accuracy of the probe before saving the constants.

6. Check the accuracy of the probes with the thermometer and water of varying temperatures. Choose "B" and press "RETURN." The temperatures of both probe one and probe two will be displayed in the lower left part of the screen. If the probe accuracy is acceptable (one or two degrees is the best you can do), press any key to return to the main menu.

7. Save the constants on the Temperature Grapher disk by choosing "C." Type "C" and press "RETURN." The program will display your newly calculated constants. If these indeed are the constants you wish to save, you must type "Y." Typing any other key will return you to the main menu without saving the new constants.

   If you try to end the program without saving the new constants on the disk, the program will remind you of this and ask if you are sure you wish to quit. If you are, type "Y." Pressing any other key will return you to the main menu.

   Important: You must calibrate both probes at the same time. Do not try to calibrate only one probe.

Tips for maximum accuracy

The temperature probes should be at the same temperature as the thermometer when you type the temperature on the computer. Wait at least 30 seconds; waiting longer will not hurt. The tips of the temperature probes should be next to the bulb of the thermometer.

Remember, if you switch a set of probes from one computer to another, the calibration will not be accurate. If you use a set of probes with a different Temperature Grapher disk, the calibration constants saved on it will not be right for those probes. In both these cases, CAL must be run again and the new constants saved to ensure accuracy.

Saving a Graph Display

You can have your Apple save a copy of any graph display and redisplay it later. To do this follow these instructions:

When the graph you wish to save is on the screen, return to the Graphing Menu by typing M. If the graphing is not continuous, you may type Y in response to "QUIT Y OR N" at the end of one pass.

From the Graphing Menu, type M and press "RETURN" to return to the Temperature Probe Menu. Now type E and press "RETURN" to end the program.

To save the graph, type the following command: BSAVE GRAPH1,A$2000,L$1FFF -- then press "RETURN."* The disk-drive should light up and whir for a few moments. The Apple is now saving the memory image of the graphics screen. To see it again immediately, type: POKE -16304,0 -- then press "RETURN." To return to text display, simply type: TEXT -- then press "RETURN." To go back to Temperature Grapher, you must restart the program by typing: RUN HELLO -- then press "RETURN."

Displaying a Graph Saved on Disk

You cannot display a saved graph from within the program. To display a saved graph you must stop the program. Choose the "END" option from the Temperature Probe Menu.

To get the graph from the disk, start by typing HGR to turn on the high-resolution graphics screen. Don't worry if there is already a graph there--your saved graph will replace it.

To get your graph, type: BLOAD GRAPH1 (or whatever name you gave the graph you want to display) and press "RETURN." Once again, the disk drive will turn on and whir for several moments (it is loading your picture into memory). As it reads your graph in, it will be partially displayed on the screen. If you want the full screen displayed (replacing your text lines on the bottom of the screen with the lower part of the graph), type: POKE -16302,0 -- then press "RETURN." To return to text, simply type TEXT and press "RETURN." Remember, if you are in full screen graphics, your typing will not be displayed until after you press "RETURN."

Also remember that you are not in the Temperature Grapher program. To start up Temperature Grapher you will have to type: RUN HELLO and press "RETURN." When you do this, you will lose your graph. For further explanation of these commands, see your Apple manuals.

* If you are saving more than one graph on a disk, you will have to give each graph a different name (otherwise each "Graph1" will erase the previous one), e.g., Graph1, Graph2, Graph3, etc. Of course, you may use any name you choose.

Printing the Graphs

The graph images can be printed if you have a printer capable of printing high-resolution screen images. See the manuals for your printer and printer interface card to find out if this is possible.

Energy-related Experiments

In this section, we would like to sketch out a series of experiments, using the temperature probes, that illustrate some concepts that are important in energy education. Temperature and thermal energy (heat) are closely related but distinctly different concepts that are hard for most people to distinguish. One of the reasons for the confusion is that temperature is far easier to measure than thermal energy but the two are often closely linked. For instance, if you raise the temperature of something, you undoubtedly also raise its thermal energy. However, the two concepts are different, and the following experiments are designed to illustrate these differences in the context of energy issues that bear on home heating and cooling.

Explorations of Heat Flow

We recommend always starting students off with the apparatus in an exploratory mode. Ask them what the probes measure, where they are sensitive, and how they can get the highest and lowest readings. For this initial work, students do not have to learn to control the graphing parameters; they can simply use the default values that are supplied with the program.

This exploration concerning the highest and lowest temperatures can help set the stage for later discussions of heat, temperature, and heat flow. Many students will come up with the idea of keeping a probe hot by wrapping it in some sort of insulator-- an article of clothing, such as a glove, a blanket, or perhaps insulation material. When they try this, they are often disappointed that the probe does not warm up, which it will not do since it lacks any source of heat. If the students are convinced that the probe is working, then the question is, "What is the value of insulation materials?" They can explore this by protecting the probe with, say, a glove, and then placing it in an icebox or refrigerator or outside in cold weather. Compare this to what happens when the probe is not protected by the insulation. What is happening, of course, is that insulation slows the flow of heat; the better the insulator, the more slowly the heat flows. Another interesting variant on these experiments is to put the probe into a glove on a student's hand, and then measure the temperature outside or in a nearly closed refrigerator. If the glove is watertight, try inserting it in ice water.

This and the next exercise raise the question of thermal contact and what the probe is actually measuring. If you just insert the probe into a glove that you're wearing, the probe is probably measuring some combination of your skin temperature and the air that surrounds it. If you're interested in the air alone, you have to make sure you don't touch the probe; if you're primarily interested in the skin temperature, then you have to maximize the contact of the probe with your skin and minimize the air contact. One way to do this is to tape the probe onto your skin with a small adhesive bandage, and then promote contact with the skin by placing hand lotion, oil, or petroleum jelly between your skin and the probe. This

latter strategy excludes the air and promotes thermal contact between the probe and your skin.

Another surprising discovery students can make when playing around with the probe is that metal, which feels as if it is cold, is at the same temperature as most other things in the room. Why does it feel colder and yet measure the same temperature? One possible explanation might be bad thermal contact: you place the probe on the metal, but it in fact has very little surface contact area and is therefore largely reading the air temperature near the metal. That argument can be tested (and disproved) by experiments using a paste or oil that excludes air and promotes thermal contact. The metal will always register room temperature unless it is heated or cooled in some external way, and the question remains: why does it feel cool?

The answer is the same as the explanation for a piece of foam plastic feeling hot to the touch. It requires an understanding of heat flow. The skin, where your temperature sensors are, is sandwiched between a heat source--the body, which has an internal temperature of about 37 degrees Celsius--and the object you are touching. If you stop all heat flow from the surface of your finger with a piece of foam plastic, which is a good insulator, then the skin warms up to 37 degrees, which is warmer than it normally is when it is naturally cooled by room air. Thus, foam plastic feels warm to the touch, because the heat of your finger is retained by it on your skin. Similarly, if you touch a piece of metal, which is an extremely good conductor of heat, it encourages the heat to flow away from your skin and cools your skin down to room temperature. Thus, metal feels cool.

The human finger could be simulated with a simple model that would illustrate this effect on the computer. Mount a probe near a weak heat source, such as a flashlight bulb, with tape or rubber bands. With the light on, let the probe reach its equilibrium temperature in the air. Then surround the probe with a piece of flexible foam plastic. The probe temperature should rise just as your skin temperature would. Similarly, bring a piece of metal into contact with the probe, and promote thermal contact with oil or petroleum jelly. The temperature of the probe should drop, the way your finger temperature does when you touch metal. If you have different metals, determine--by touch--which of them feels coolest, and then see whether your experimental model of the finger matches the order of coolness you perceive.

In the discussion above, we have assumed that room temperature is below body temperature. What do students think will happen when the reverse is true, when the ambient temperature is above body temperature, as sometimes happens when you get into your car on a hot summer day? Then good insulators feel cooler than good conductors. If the seat touches your skin directly, you are far less comfortable than if you are protected from the seat by a layer of clothing, because the clothing slows the conduction of heat. Furthermore, you cannot bear to touch anything metallic, even though it is probably at the same temperature as the seat, because it conducts heat to you quite rapidly.

Thermal Conductivity Measurements

The next experiment you might undertake would be to measure qualitatively the ease with which different materials transfer thermal energy, a characteristic referred

to as their thermal conductivity. Get a cup of hot water and graph the temperature as it cools in air. (A Styrofoam coffee cup is ideal.) Note the shape of the cooling curve. It is the shape of a negative exponential, cooling quickly at first and then more slowly as it reaches room temperature.

Ask students how long it takes to cool down. Because the cooling rate slows as room temperature is reached, it is difficult to assign a specific time that it takes to cool. One measure could be the "thermal half-life," which is the time it requires to cool halfway from its initial temperature to room temperature.

To measure the thermal half-life, have the students fill a Styrofoam coffee cup with hot water. Then, record the time it takes for the temperature to drop to the halfway point between the initial and room temperatures. To get an accurate measurement, do this several times and take the average of the measurements. Once you have a quantitative measure like the thermal half-life, you can investigate the factors that influence it. Try measuring the thermal half-life with the same amount of water at different initial temperatures. As long as the cup and volume of water stay the same, you will find the thermal half-life to be approximately the same. The students may come up with Newton's Law of Cooling: "The rate of cooling is proportional to the difference in temperatures." One very important factor is evaporation, which you can largely eliminate by covering the cup with a lid. Even a non-insulating lid has a large effect, although an insulating lid is even better, as students can discover.

Using an insulated lid, investigate how the quantity of liquid determines the length of time to cool. Students will discover that the more liquid there is, the longer it takes to cool, because there's more heat that has to pass out through the same container.* The effect is not as linear as you might like it to be, since as you put more material in, it comes up higher in the container and thus has a larger effective area through which heat can flow. Doubling the amount of water, then, does not quite double the length of time it requires to cool. One way to see this better is to keep the water level constant in your container, while changing the volume by filling part of the volume with a ping-pong ball or a piece of foam plastic glued to the bottom of the cup. See Figure 2.

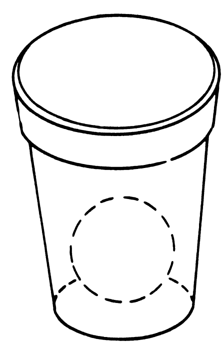

Figure 2

* In other words, thermal energy is a function of "stuff" (mass) and temperature. The more stuff there is at the same temperature, the more thermal energy that stuff holds.

Next, students can investigate the thermal conductivity of different materials, keeping the water volume constant and always insulating and covering the top. It is important to find a cup that is the best insulation. Try a double or triple Styrofoam cup. Make a contest out of this, and give every student the same amount of equally hot water one day, and then measure its temperature an hour or a day later with the computer. The student with the warmest water wins.

Studies of Evaporation

Up to this point, we have tried to minimize the effect of the cooling caused by evaporation. It is important at some point to encourage students to investigate this effect. Cooling by evaporation is the primary means by which we cool ourselves and is a major source of building cooling, particularly in low-humidity areas.

An absorbing project laboratory can be built around the question, "How cold can you get the probe from evaporating room-temperature water?" Students can try pans of water, large and small amounts, wicks, blowing on the water with fans, and any other ideas that come to them. On any given day, there is a lowest temperature students can reach, no matter what their approach is. On humid days, this may only be a few degrees below room temperature. On dry winter days, this may be ten or more degrees below room temperature. This lowest temperature they get is referred to as the wet-bulb temperature and, together with room temperature, can be used to determine the relative humidity. The wet-bulb temperature traditionally is measured with a wet-bulb thermometer (illustrated below). This is a thermometer with a fabric wick around the bulb of the thermometer. The other end of the wick is in the water. See Figure 3.

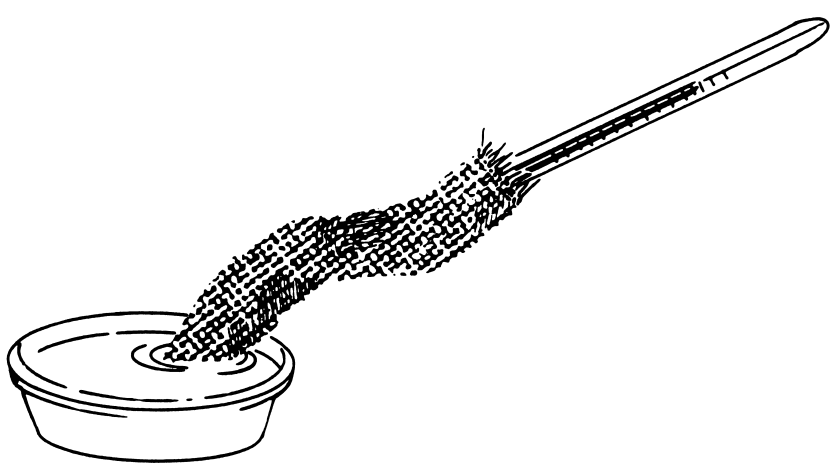

Figure 3

As a second project, have students figure out the warmest temperature glass that will cause condensation. A glass of ice water will almost always be wet on the outside, owing to condensation of water from the atmosphere.* On the other hand, a glass of room-temperature water will not cause condensation. Thus, there must be some intermediate temperature at which condensation just occurs. What is that temperature? While the experiment is under way, have students measure both the internal water temperature and the temperature of the condensing water on the outside of the glass.

If these experiments are done carefully and on the same day, or on days with the same relative humidity, students will find that the dewpoint and the wet-bulb temperature are the same. It is interesting to have students speculate on the connection between the two; perhaps they will come up with the idea that evaporation will happen only when the dewpoint is below room temperature. Conversely condensation will only happen where the temperature falls below the dewpoint. Ask what they think might happen if the temperature of the whole room fell below the dewpoint. Have they ever seen anything like this outside in the morning?

Repeat the experiments on different days to investigate the relation between humidity and the wet-bulb/dry-bulb temperature difference. Another interesting experiment is to allow evaporation in a closed container. Eventually, depending on the size of the enclosure, evaporation stops, because the air can hold no more water. Have students try their wet-bulb experiments in a Styrofoam cup, filled largely with water and covered on top. They should see evaporative cooling only when the container is first covered. Eventually, the wet-bulb temperature will reach the temperature of the water. At this point, the air above the water is saturated.

Other interesting experiments involve repeating some of these measurements with other liquids. Look for evaporative cooling from rubbing alcohol and cooking oil. If you try other substances, be careful of fire hazards and avoid powerful solvents that might dissolve the insulation on the temperature probe or damage the Styrofoam cups.

State Changes and Energy

This series of experiments involves investigations in which there is a change of state. For this experiment, we suggest using sodium thiosulfate, which can be obtained from a chemical supply house or from a photography store as crystals with the generic name hypo or fixer. Hypo is used in the final step in film development to remove unused iodide from films and printing paper.

Place the crystals in a test tube, place the test tube in boiling water, and warm the crystals until they melt into a liquid. Remove the test tube, insert the temperature probe, and record the temperature of the liquid as a function of time as it cools in air. At one point, the hypo will stop cooling; it may even warm up. It will then stay at a constant temperature until the liquid is fully converted to a solid, and then the cooling will continue. You will see on the graph of

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* What would you be wearing if a glass of ice water did not have any water condensing on the outside? Probably a warm coat because of the cold, although you might be in a desert where there is <u>no</u> moisture in the air to condense on the glass.

temperature against time a distinct plateau at the melting temperature of the hypo. You may see supercooling, which is the initial cooling of the liquid below the melting temperature and the sudden warming as solidification occurs.

Through a series of discussions or experiments, students should come to the conclusion that heat is being released while the substance solidifies, but that the temperature does not drop. Conversely, although this is harder to measure, they can see that heat can be put into the hypo while it does not rise in temperature but rather is converted from a solid to a liquid. This effect has a practical application in low-temperature solar heating systems. These systems can produce a lot of water heated to 40 degrees Celsius, but once the storage has heated up to 40 degrees, no more thermal energy can be saved. Heat will only flow where there is a difference in temperature. If the storage is a material that melts at 35 degrees Celsius, it is a different story. Heat will continue to flow from the water heated by the solar panels into the storage until the storage material is completely melted. The temperature of the storage material will not rise above 35 degrees until this has happened. Hypo is not used for this, but rather another low-temperature melting solid known as Glauber's salt.

Heat Capacity Measurements

The next two sets of experiments use simple algebra. The concepts can be understood and the experiments done qualitatively, without the math, so read on and don't be intimidated. This set of investigations examines the ease with which different substances are warmed or cooled. If you mix equal amounts of water at 10 and 30 degrees, it is pretty obvious that the resulting mixture should be at 20 degrees. But what happens if you mix 10-degree water with 30-degree oil in equal amounts? It is easier to change the temperature of oil than that of water, so the final temperature of the mixture will be below 20 degrees. Using this idea, one can compare the relative ease with which all kinds of liquids and solids can be heated or cooled.

This again has application in any situation in which the object is storing a lot of heat without getting hot. In addition to thermal storage in a solar heating system, this is also an important property in cooling engines. Water is an ideal coolant because it is so difficult to heat and thus can keep the cylinders in your engine cool. As you can determine from experimentation, antifreeze is easier to warm than water and really should not be used for high-temperature driving.

There are two qualities you may measure in these experiments: heat capacity and specific heat. Both refer to the amount of thermal energy it takes to raise a substance one degree. Heat capacity is measured in calories per degree per unit volume. Specific heat is measured in calories per degree per unit mass. In fact, a calorie is defined as that amount of energy required to raise one gram of water one degree Celsius. This makes the specific heat of water equal to one by definition. To convert heat capacity to specific heat, use these equations:

$$\text{Heat Cap. (substance X)} = \text{(Heat Sp.) (Density)}$$

$$\text{Heat Sp. (substance X)} = \frac{\text{Heat Cap.}}{\text{Density X}}$$

$$\text{Density} = \frac{\text{Grams}}{\text{cm}^3}$$

You may also refer to the heat capacity of a specific amount of material. This would be the number of calories needed to raise its temperature one degree Celsius.

Measuring the heat capacity of a particular substance is a little more difficult than measuring the calories going in and then recording the rise in temperature. It is easy for us to measure temperature with Temperature Grapher, but there is no such thing as a simple calorie meter. Let's think about the original experiment now. When equal volumes of water are mixed together at two different temperatures, an equilibrium temperature is reached that is exactly halfway between the two initial temperatures. We can say that the amount of heat one volume of water lost as its temperature dropped is exactly equal to the amount of heat the second volume of water gained. If you mix a volume of water at temperature T_1 with an equal volume of liquid X, of unknown heat capacity at temperature T_2, after a while the temperature will stabilize at T_e. The heat lost by the water can be calculated with the equation:

$$\Delta Q_{water} = (T_1 - T_e) \text{ (Heat Sp. water) (Density water) (Vol. water)}$$

$$\Delta Q_{water} = (T_1 - T_e) \text{ (Heat Cap. water) (Vol. water)}$$

Using our earlier principle of equivalence of heat transfers, the amount of heat absorbed by liquid X must be equal to the heat lost by the water:

$$\Delta Q_{water} = -\Delta Q_{liquid\ X}$$

Substituting, we find--

$$-\Delta Q \qquad = (T \quad - T\ ) \text{ (Heat Cap. liquid X) (Vol. liquid X)}$$

The only unknown in this equation is the heat capacity of liquid X, which is just what we were trying to find:

$$\text{Heat Cap. liquid X} = \frac{-\Delta Q}{(T_2 - T_e) \text{ (Vol. liquid X)}}$$

These equations may be modified to use mass and specific heat instead of volume and heat capacity. The heat capacity of solids may also be measured this way. The mass or volume of the solid must be measured accurately and a longer time must be given for the water and solid mixture to reach equilibrium temperature.

Insulation Measurements

In the next experiments, students get a quantitative measure of the insulation ability of different materials. This property is called the R-value and has much the same role as resistance in electrical circuits. The idea behind these experiments is to put a fixed amount of hot water on top of the material you are measuring and arrange things so that the only way the water can cool is by passing heat through the substance under test. The rate of cooling of the water tells you how quickly heat is being transferred away from the water by the material under test. If the water cools quickly, the material is a poor insulator and will have a low R-value. Conversely, if the water cools slowly, the material is a good insulator and has a high R-value. The results of these experiments can be either qualitative or quantitative, depending on the mathematical sophistication of the students.

We suggest getting two sheets of 1" Styrofoam and a watertight, fast-drying glue that does not attack the plastic. Suppose you wanted to test the insulation of a pane of glass. Remove a 4"-square section from one piece of Styrofoam, and bond the resulting piece to the glass, so that the glass forms the bottom of a rectangular trough. See Figure 4.

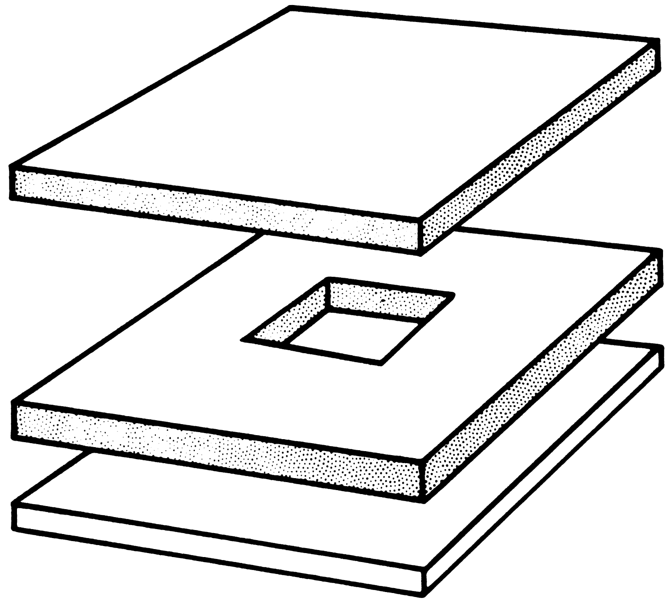
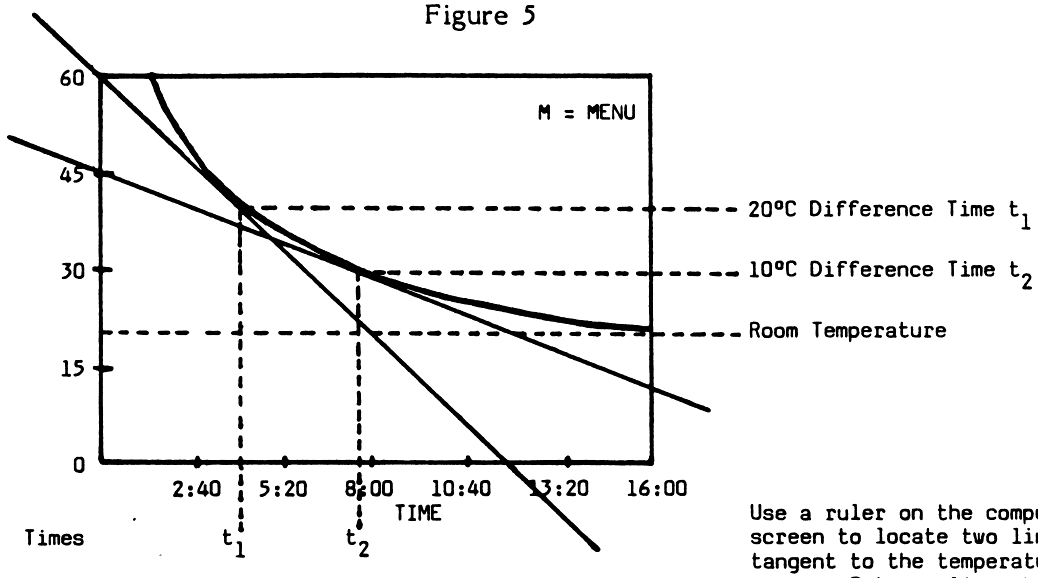


Figure 4

Place a known volume and temperature of hot water in the trough, and cover the assembly with the second piece of Styrofoam. Press the probe down through the top of the Styrofoam so that it can measure the temperature of the water. Set a fan to blow on the bottom of the glass so that it will cool to room temperature. Now record the temperature of the water with Temperature Grapher until it reaches room temperature. Select a time base long enough to include the whole experiment on one screen. If you run this experiment with different materials, comparing the amount of time the water takes to drop to room temperature will tell you which material has the greatest R-value. The material with which the water took the longest to drop to room temperature will be the one with the highest thermal resistance.

To calculate the R-value for a particular material, use the graph on the screen to approximate the cooling rate in degrees per second. Do this at several different intervals of temperature. (See illustration on following page.)

Figure 5



Use a ruler on the computer screen to locate two lines tangent to the temperature curve. Put one line where the temperature difference is 20° from room temperature and one at 10° from room temperature. Use these lines to estimate the cooling rate in degrees C per minute.

Estimated cooling rate:

at time t_1 the slope of the curve = $\dfrac{60°}{12\text{ min.}} = \dfrac{.083°}{\text{sec.}}$

at time t_2 the slope of the curve = $\dfrac{30°}{16\text{ min.}} = \dfrac{.03125°}{\text{sec.}}$

Now use the cooling rate, the mass of the water, and the specific heat of water to calculate the thermal energy flow, Q, in calories per second.

$$Q = (\text{cooling rate})\ (\text{mass})\ (\text{specific heat of water})$$

$$Q = \left(\frac{°C}{\text{sec.}}\right)\left(\text{grams}\right)\left(\frac{1\text{ cal.}}{\text{gram }°C}\right)$$

$$Q = \frac{\text{cal.}}{\text{sec.}}$$

With Q, the thermal energy flow through the glass, calculated for several different intervals of temperature, you can calculate the R-value with this equation:

$$R = \frac{(\text{Area})\ (\text{Temp. Difference})}{\text{Heat Flow}}$$

$$R = \frac{A\ \Delta T}{Q}$$

Area is the area of the glass in square centimeters. Temp. Difference is the difference in degrees Celsius between room and water temperature.

The R-value you calculate this way will be one based on the metric system. The values you may see on building materials in this country will be based on the English system of measurement.

To calculate this R-value, use the Btu, the hour, and the square foot as our units of measurement.

To find the R-value per unit thickness for the material you measure, use this equation:

$$\frac{\text{R-value}}{\text{cm}} = \frac{\text{R-value measured}}{\text{material thickness cm}}$$

With this simple approach, the R-value of many materials can be measured with a moderate degree of accuracy.

Very good insulators cannot be measured this way, however, because the process only works if the dominant means of losing heat from the water is through the material under test. If the material is an extremely good insulator, a significant amount of the heat will be lost through the Styrofoam and the measurements will not be valid.

To measure materials that are not watertight, cover them first with a layer of plastic wrap. Some oil or petroleum jelly may be required between the material under test and the plastic wrap in order to promote thermal conductivity.

Have students test common building materials: wood, rock, concrete, slate, glass, metal, plasterboard, plaster, plywood, and the like. Also try double and triple panels, separated by air. You can omit the R calculation if students cannot handle the math. Students can also investigate the effect of different sizes of water troughs and different thicknesses of materials. These two factors should affect the cooling rate, but not the calculated R. R-value is a property of the material, and area and thickness were taken into account in the calculation of R.